Disruptive energy futures

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Cofounder and Chief Scientist

California-Germany Bilateral Energy Conference, Sacramento, 19 Oct 2017

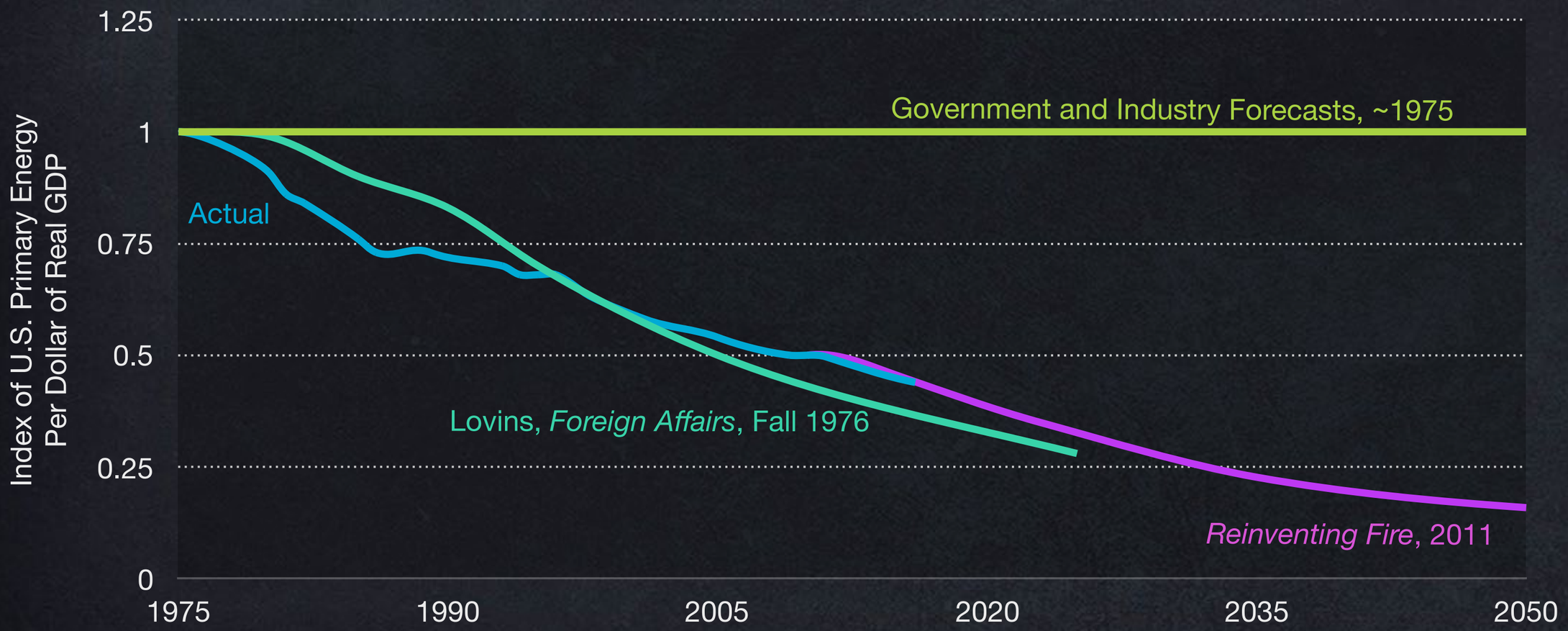
Henry Ford and Thomas Edison

“I can’t wait to see what happens when our industries merge.”

188.5610 from https://www.thehenryford.org/exhibits/pic/2004/July.asp

Heresy Happens

U.S. energy intensity, 1975–2016p



Lovins House, Old Snowmass, Colorado (1983)

U.S. buildings: 3–4× energy productivity worth 4× its cost

(site energy intensities in kWh/m²-y; U.S. office median ~293)

~277➡173 (–38%)

2010 retrofit

284→85 (–70%)

2013 retrofit

...→108 (–63%)

2010–11 new

...→≤47 (–84%)

2015 new

Yet all the technologies in the 2015 example existed well before 2005!

910-m^2 Bavarian mixed-use building produces nearly 5× as much energy as it uses

"House of Energy", Kaufbeuren, 2013, world's first Passive House Premium building: total use 21 kWh/m^2y (including 8 for heating); 250 m^2 PVs produce 103 kWh/m^2y

BAM’s unsubsidized mass retrofit of Dutch public housing

Before: 5 units, each with
annual energy bills ~€1.5–2k

After: net-zero-energy,
expected to be financed
just from energy savings
by industrializing the
€460k (soon €40k)/unit retrofit

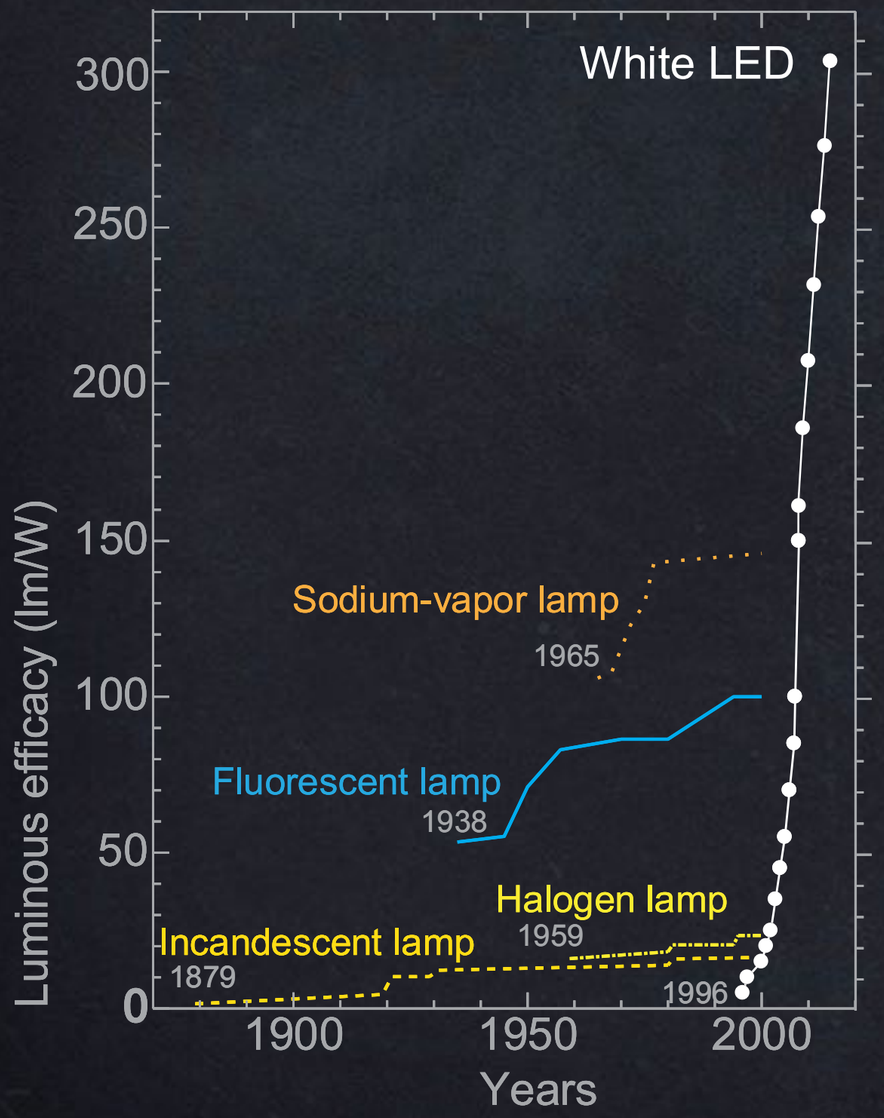
Designing to save ~90% of pipe and duct friction—equivalent to about half the world's coal-fired electricity

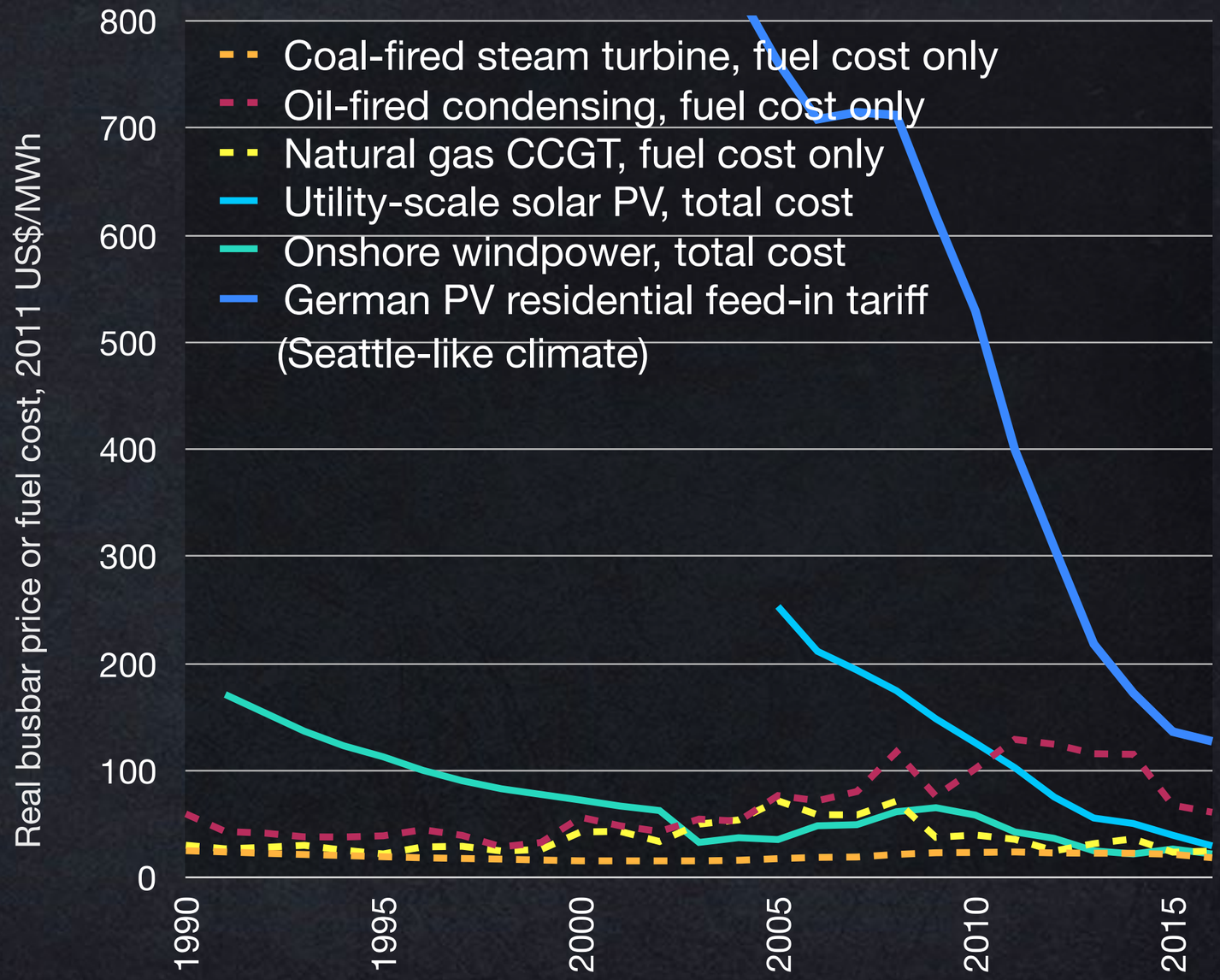
thin, long, crooked

fat, short, straight

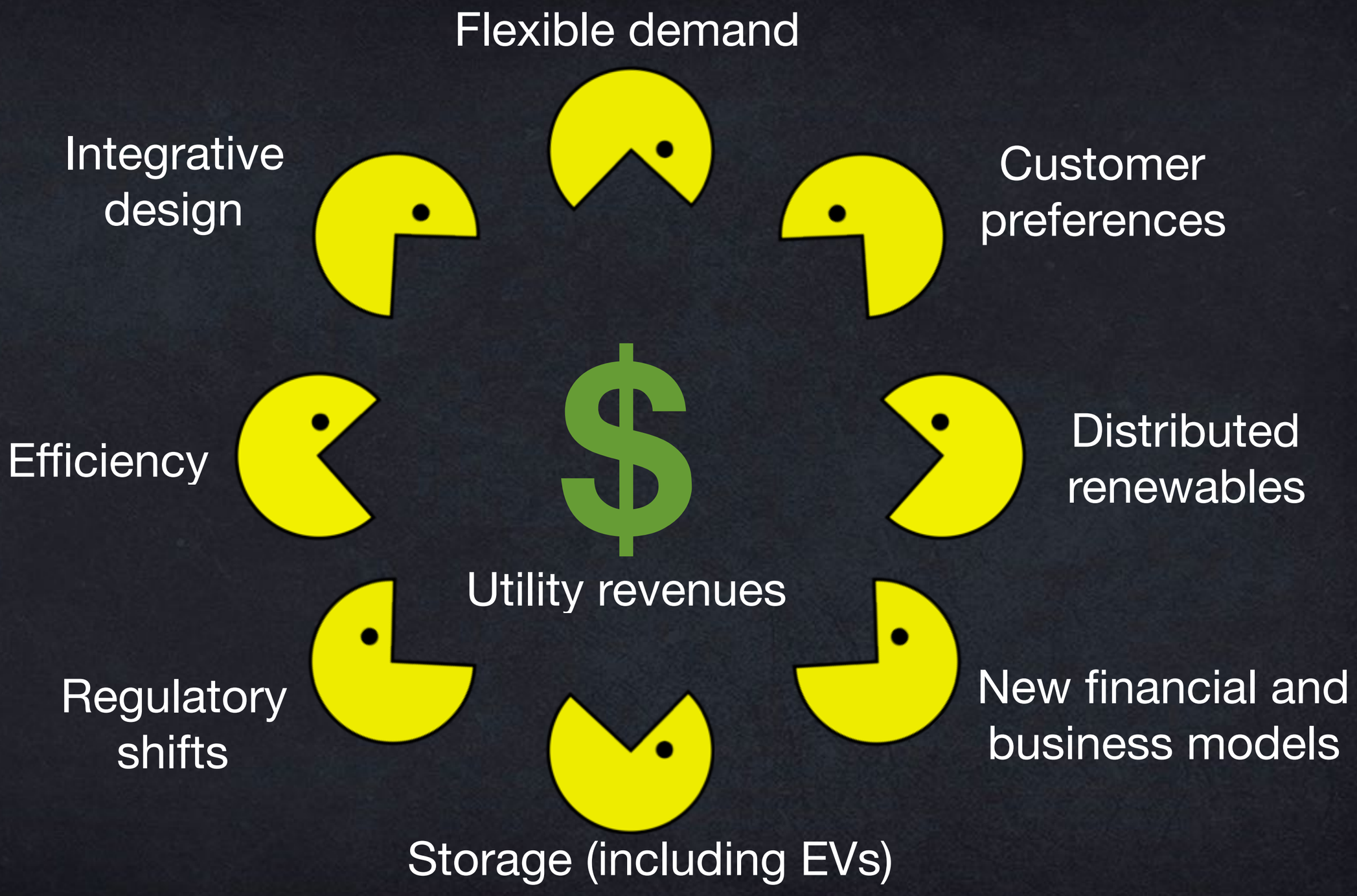
Typical paybacks ≤1 y retrofit, ≤0 new-build
But not yet in any textbook, official study, or industry forecast

LED and PV

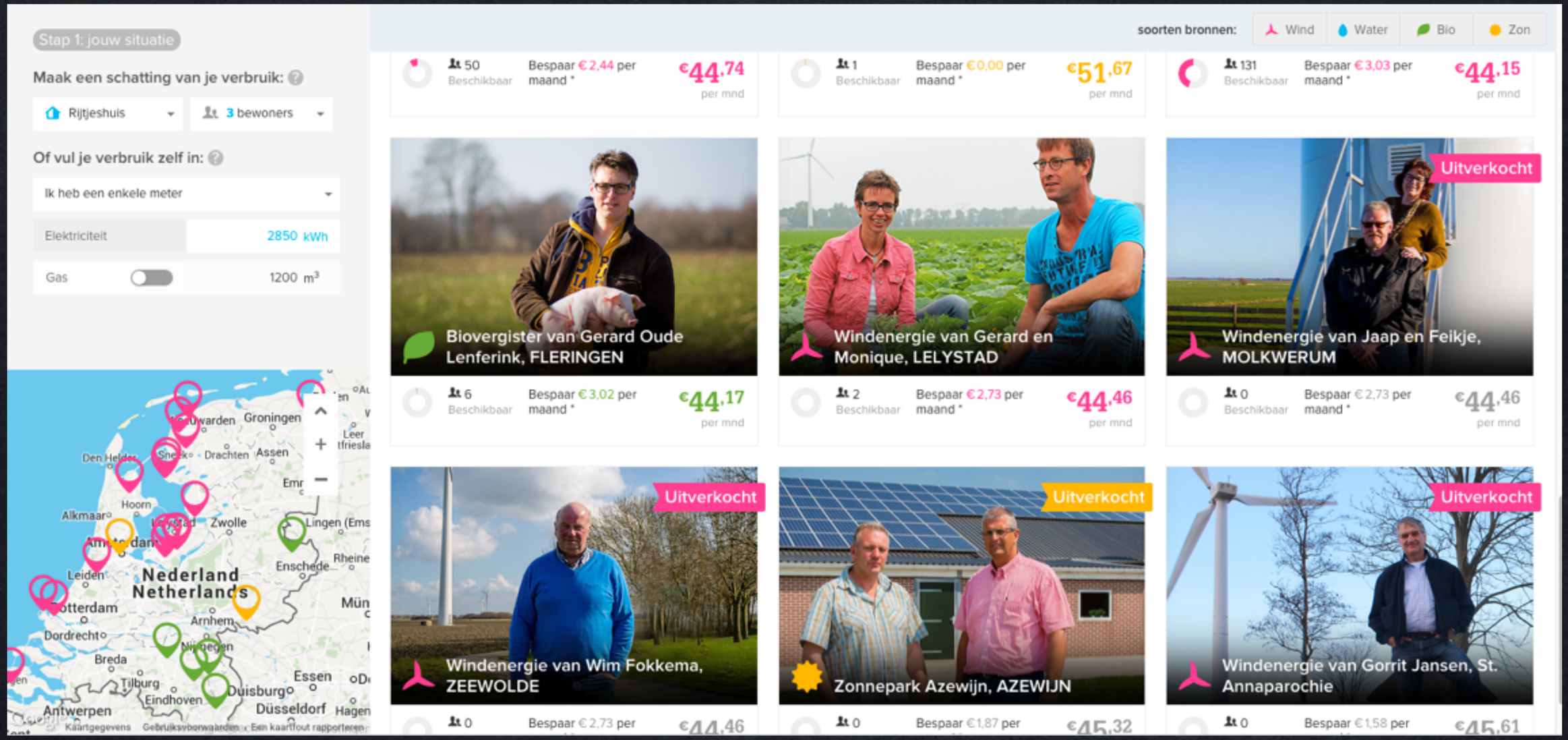




Sources: L: courtesy of Dr. Yukio Narukawa (Nichia Corp., Tokushima, Japan) from *J. Physics. D: Appl. Phys.* ***43***(2010) 354002, doi:10.1088/0022-3727/43/35/354002, updated by RMI with CREE lm/W data, 2015, www.cree.com/News-and-Events/Cree-News/Press-Releases/2014/March/300LPW-LED-barrier;. R: RMI analysis, at average 2013 USEIA fossil-fueled generation efficiencies and each year's real fuel costs (no O&M); utility-scale PV: LBNL, *Utility-Scale Solar 2013* (Sep 2014), Fig. 18; onshore wind: USDOE, *2013 Wind Technologies Market Report* (Aug 2014), "Windbelt" (Interior zone) windfarms' average PPA; German feed-in tariff (falls with cost to yield ~6%/y real return): Fraunhofer ISE, *Cost Perspective, Grid and Market Integration of Renewable Energies*, p 6 (Jan 2014); all sources net of subsidies; graph inspired by 2014 "Terrordome" slide, Michael Parker, Bernstein Alliance

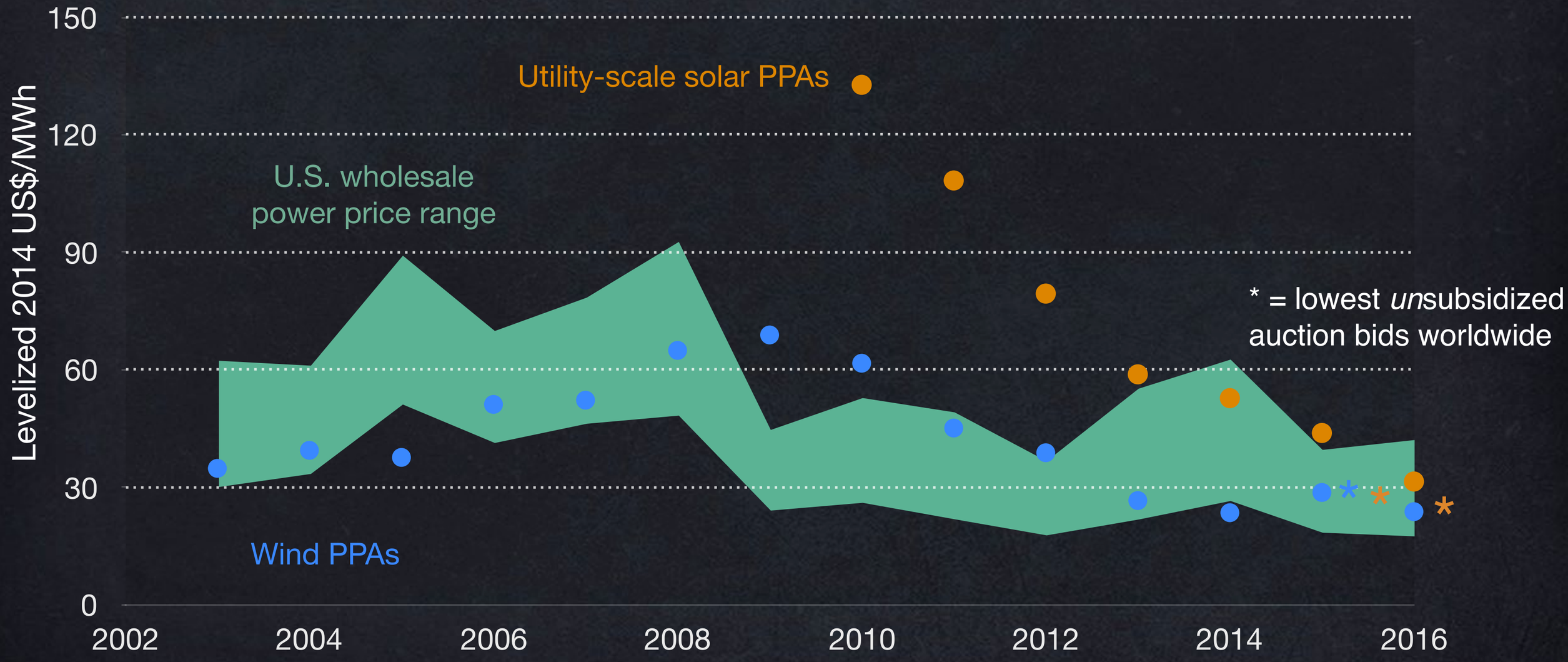

Flexible demand
Integrative design
Customer preferences
Efficiency
$
Distributed renewables
Utility revenues
Regulatory shifts
New financial and business models
Storage (including EVs)

Netherlands: community connection



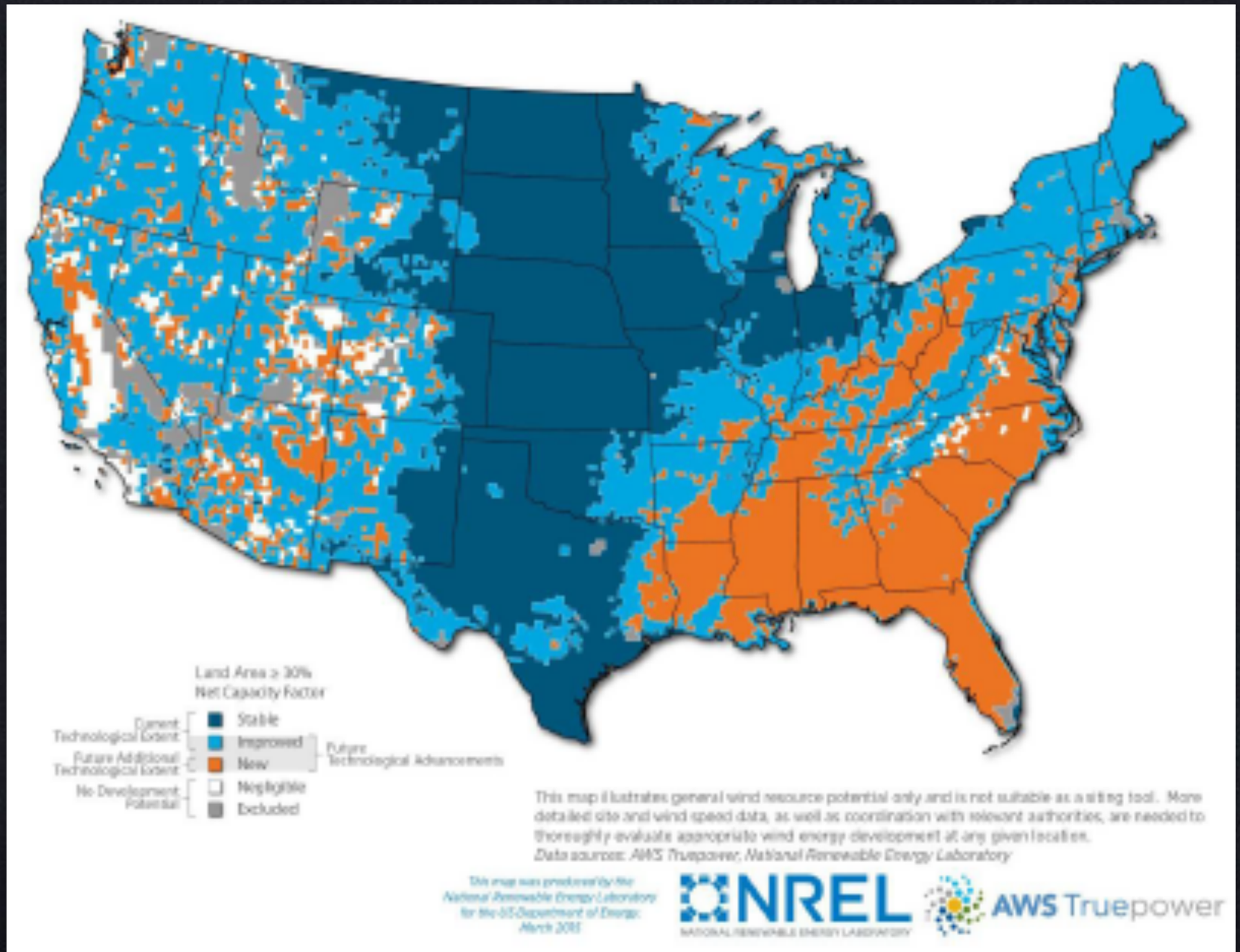
Renewable energy's costs continue to plummet

Wind and photovoltaics: U.S. generation-weighted-average Power Purchase Agreement prices, by year of signing



Updated through Mar 2017; solar asterisks: Chile (2.91¢/kWh, Aug 2016) and Mexico (2.7 ¢/kWh, Feb 2017); wind asterisk: Morocco (Jan 2016)

Best resources far away, or adequate resources nearby?



US Department of Energy,
Enabling Wind Power Nationwide,
May 2015, DOE/EE-1218

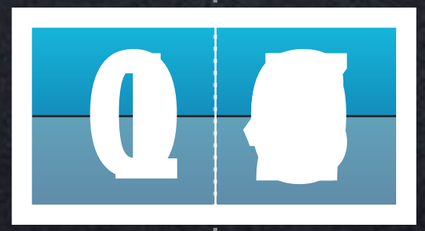
8 GW-y

“Cathedral”

Photovoltaics

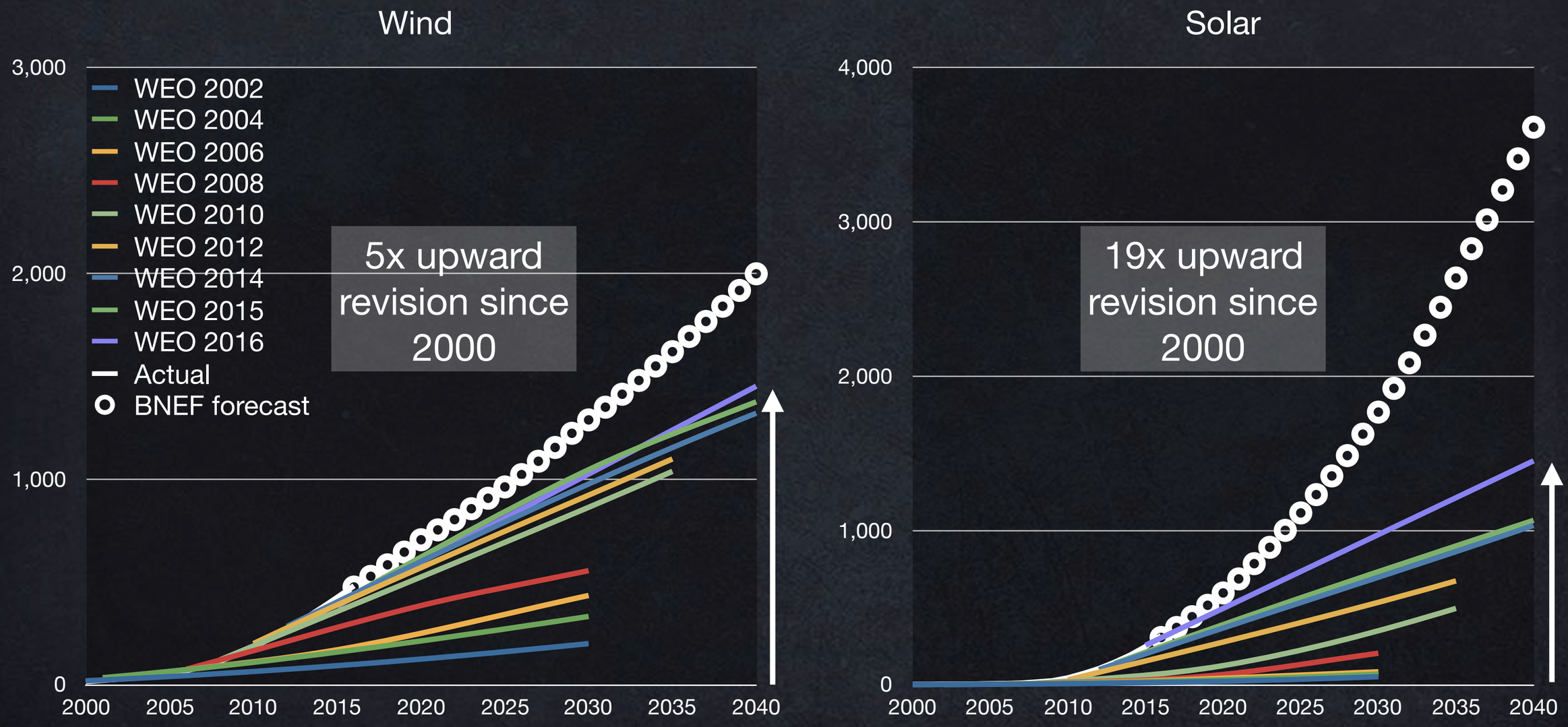
36 GW-y

Years

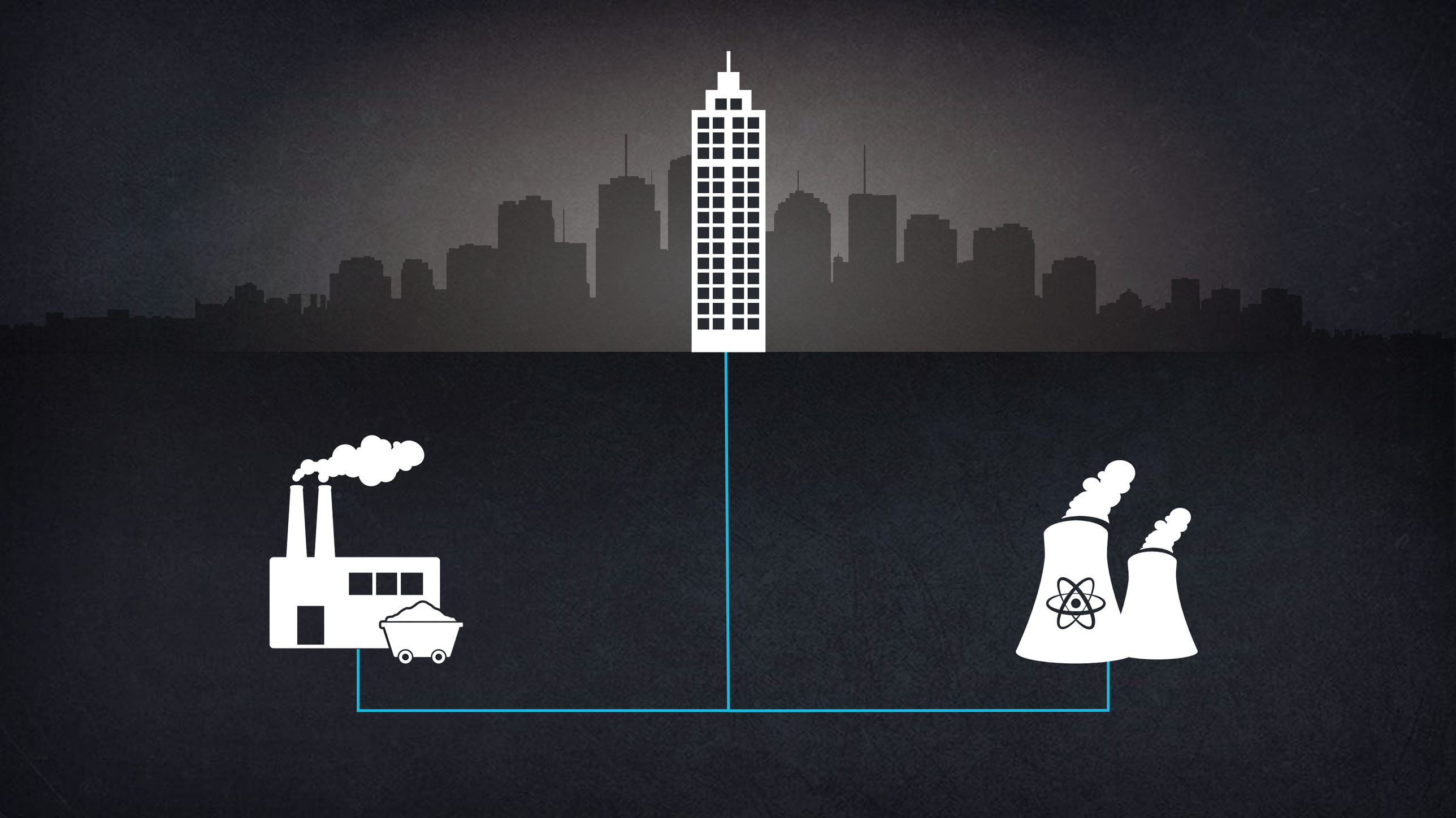


International Energy Agency global wind and solar forecasts

Cumulative GW installed

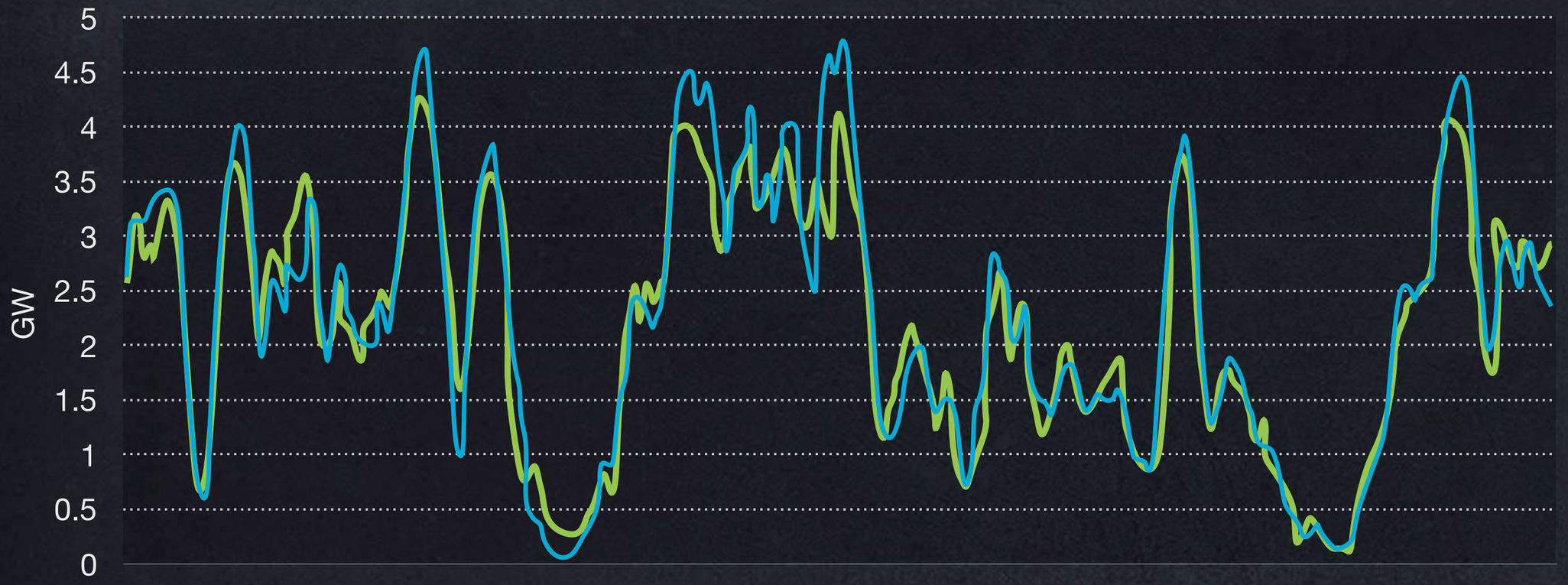


Source: IEA WEO, BNEF (forecast from June 2015), slide inspired by Michael Liebreich's 2016 BNEF Summit keynote

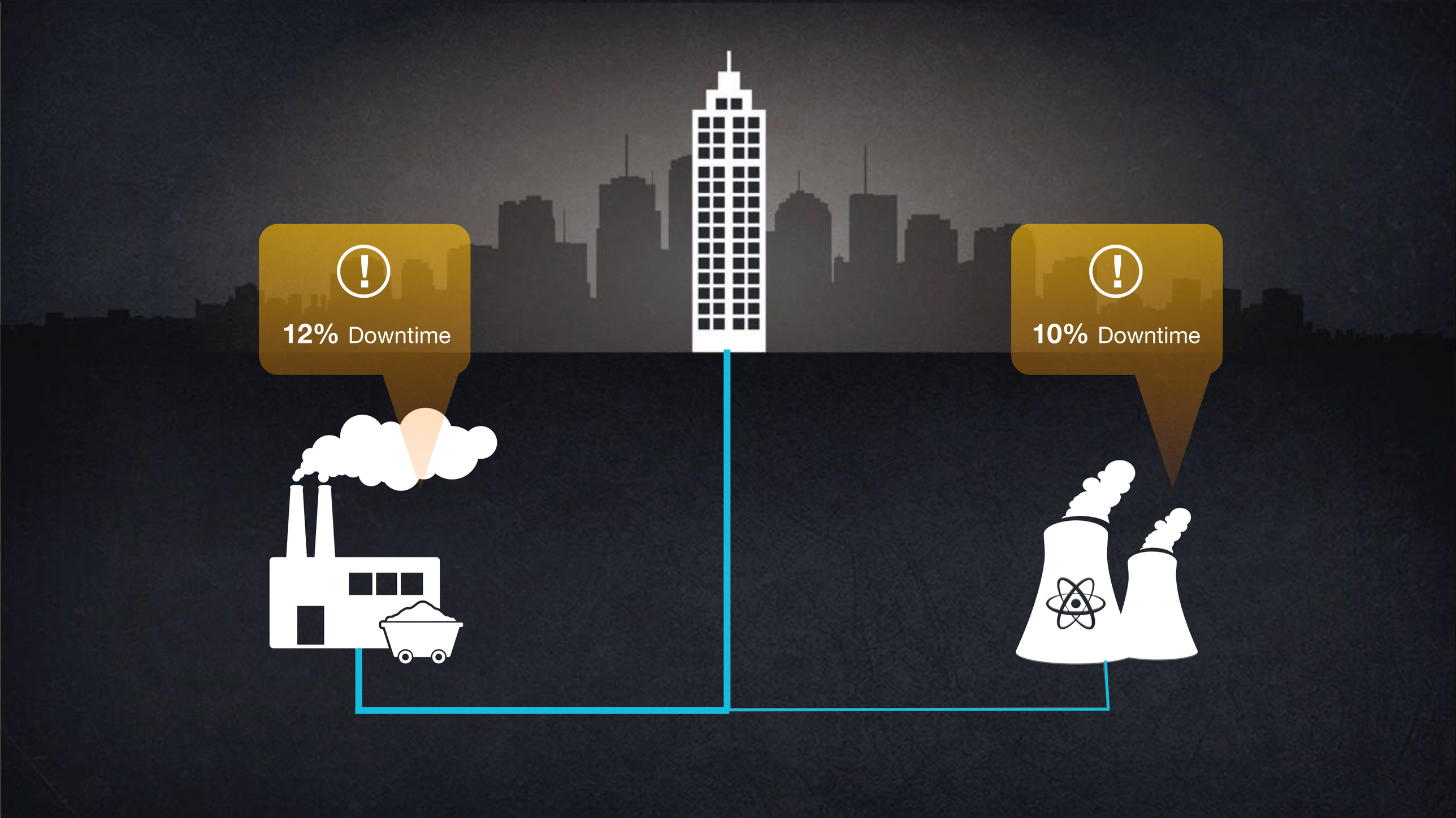


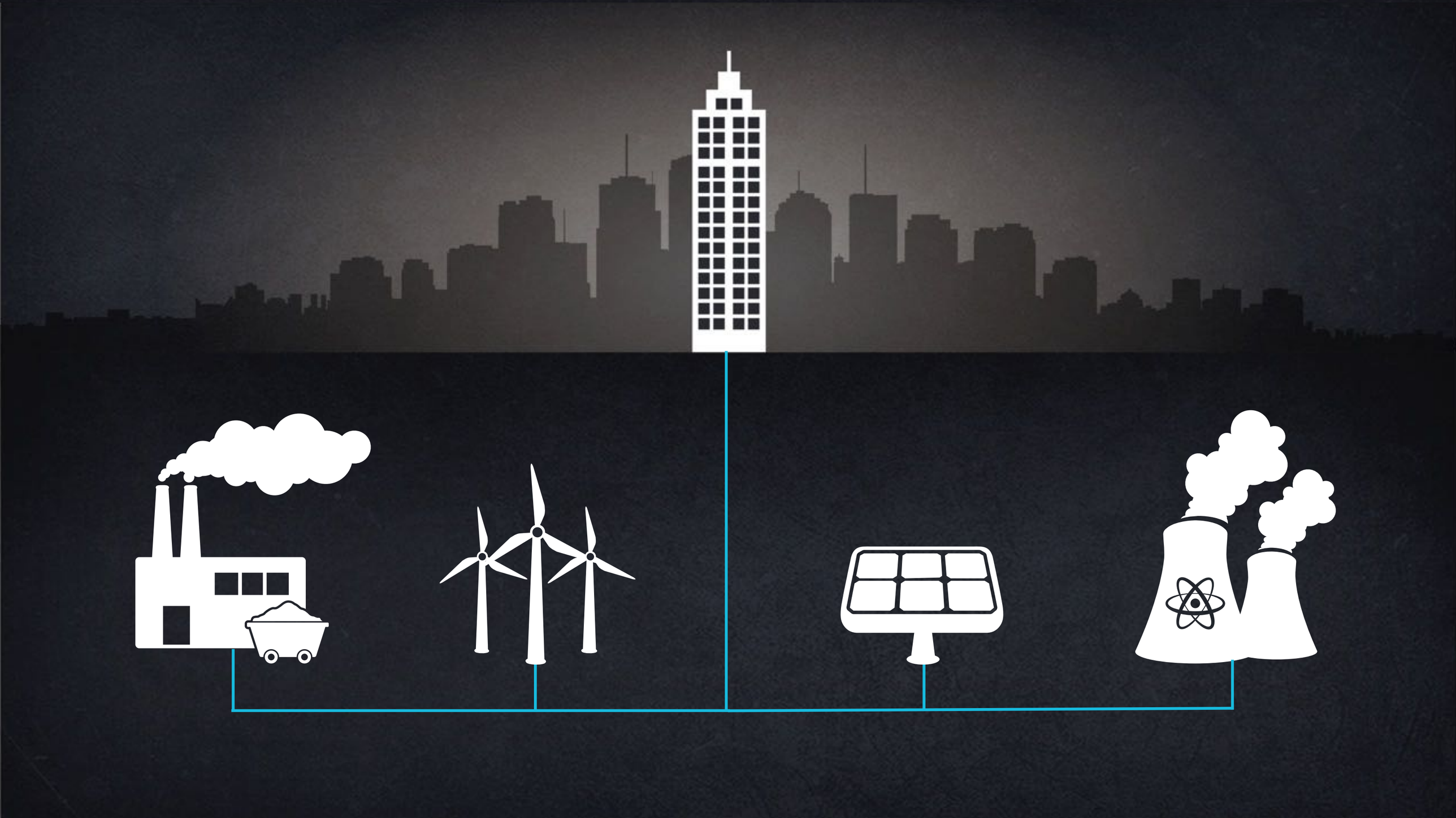
Variable Renewables Can Be Forecasted At Least as Accurately as Electricity Demand

French windpower output, December 2011: forecasted one day ahead vs. actual



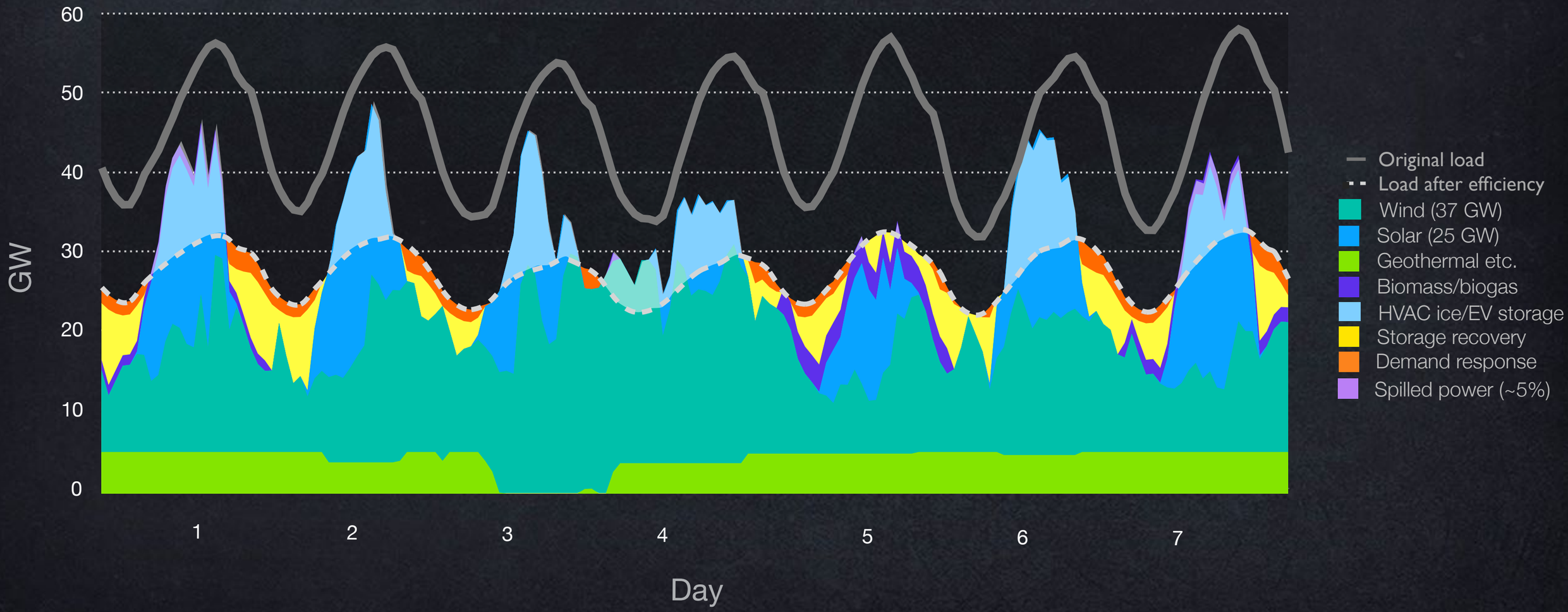
Source: Bernard Chabot, 10 April 2013, Fig. 7, www.renewablesinternational.net/wind-power-statistics-by-the-hour/150/505/61845/, data from French TSO RTE


12% Downtime
10% Downtime



Choreographing Variable Renewable Generation

ERCOT power pool, Texas summer week, 2050 (RMI hourly simulation, 2004 renewables data



Choreographing Variable Renewable Generation

59%
Europe, 2014 renewable %
of total electricity consumed

Scotland 2015 (44% without hydro)

62%

Denmark 2015 (42% wind, 11% bio) (2013 windpower peak 136%—55% for all December)

32%

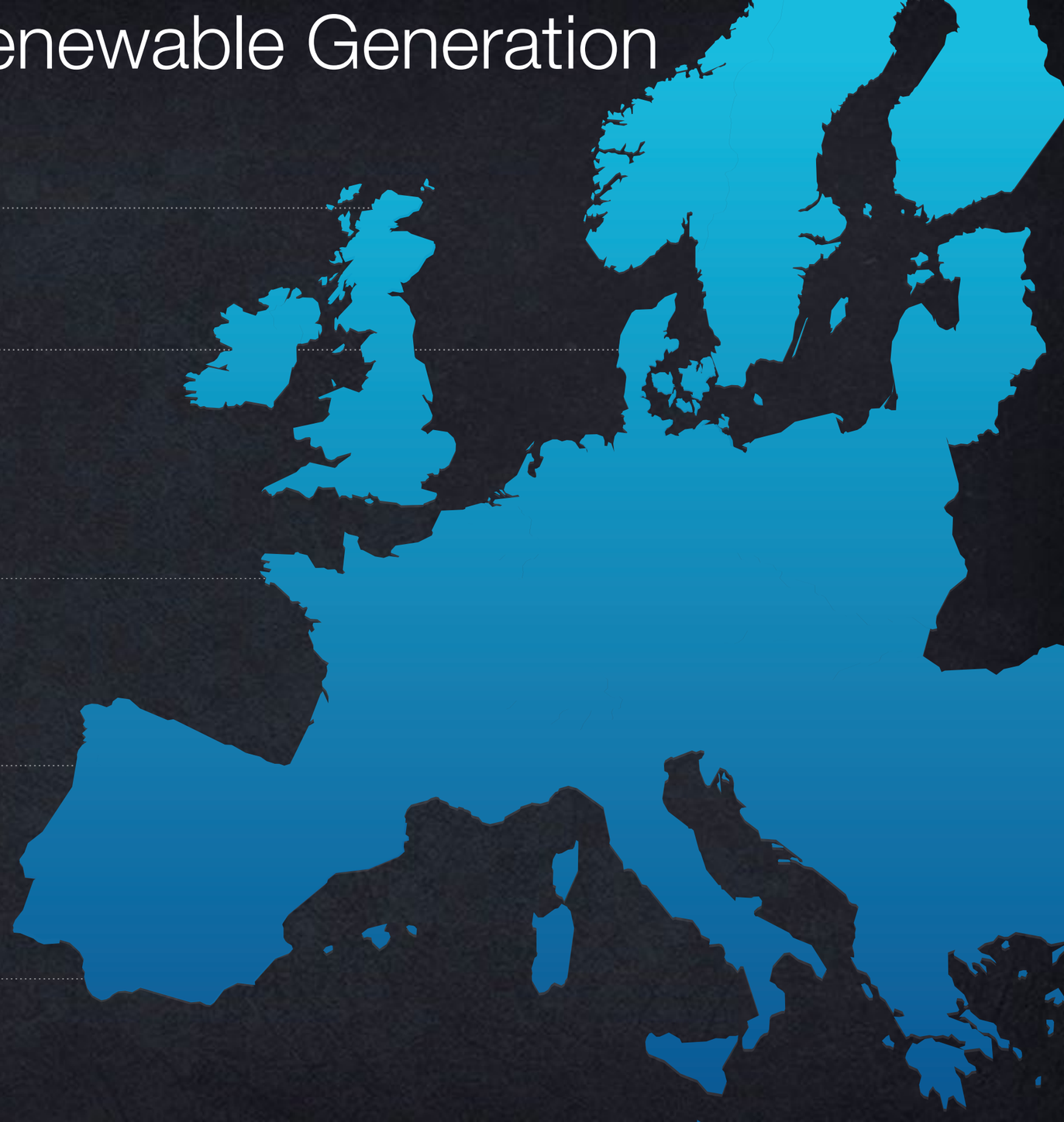
Germany 2016 (2016 peak 88%)

63%

Portugal (2016, 32% without hydro) (2016 peak 100% in 2011, 2016; 70% for 1H2013 incl,26% wind & 34% hydro)

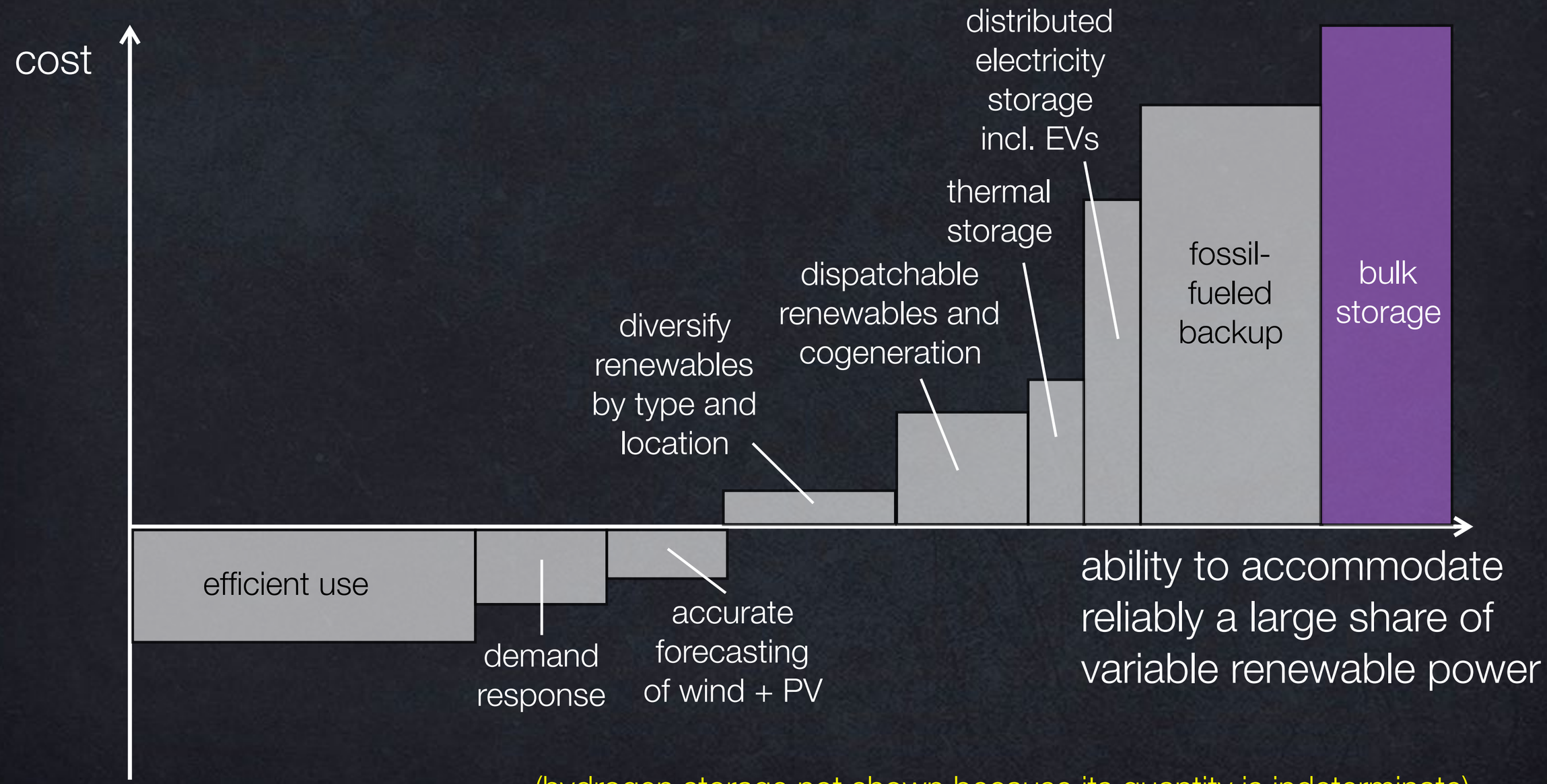
46%

Peninsular Spain (2016), 27% without hydro)



Grid flexibility resources

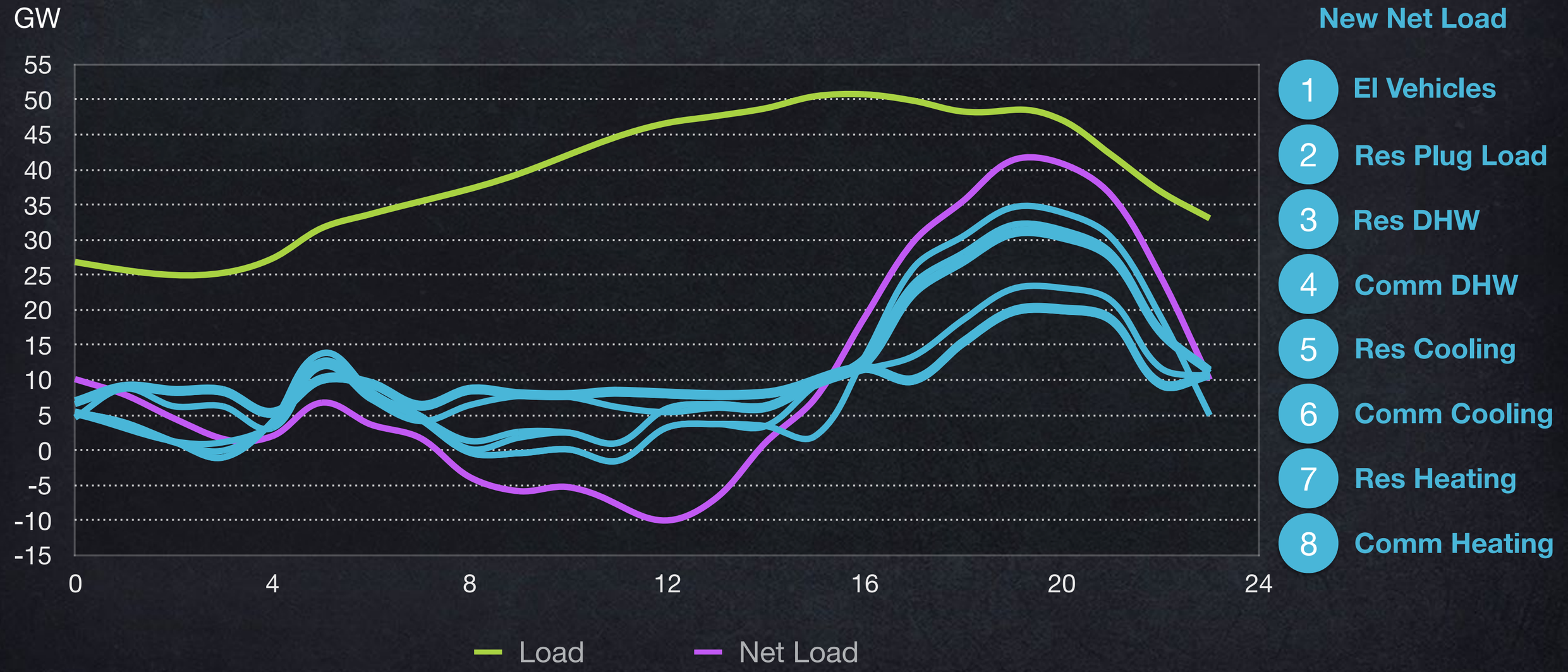
(all values shown are conceptual and illustrative)



(hydrogen storage not shown because its quantity is indeterminate)

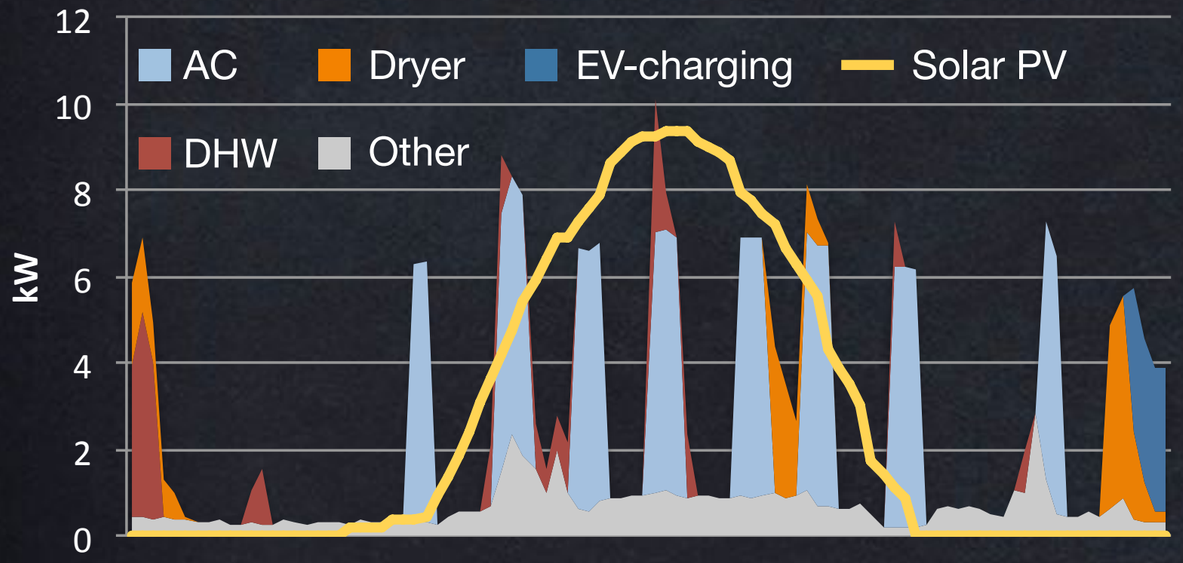
Flexible loads: goodbye “duck curve”

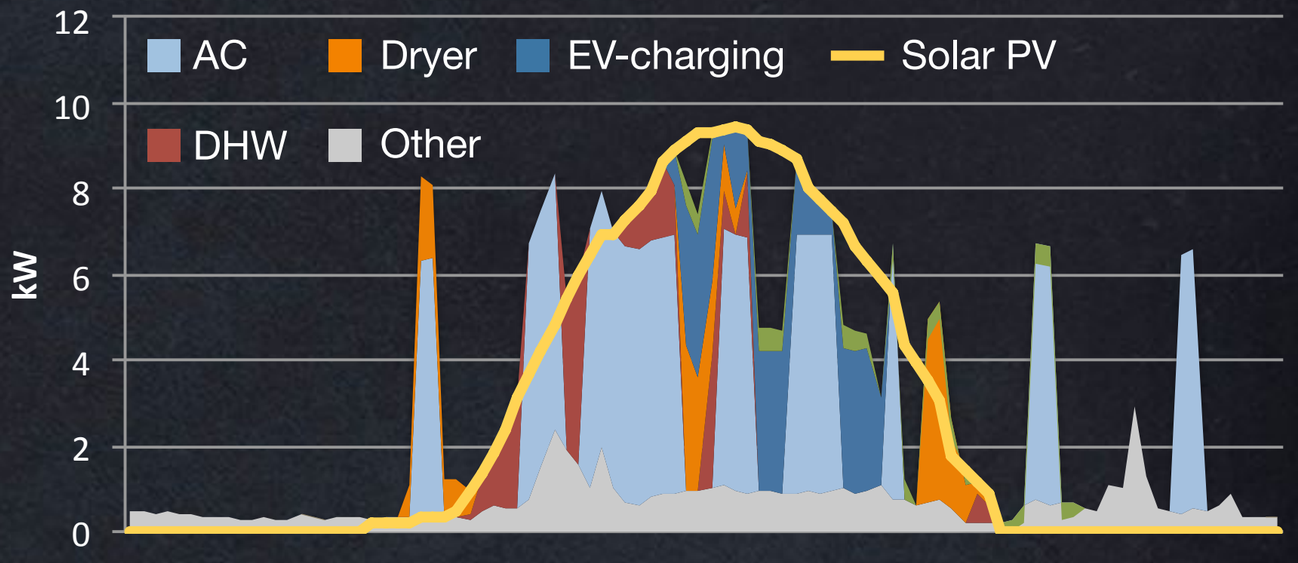
These eight levers combine to make net load far smoother and lower (ERCOT, summer 2050)



Source: RMI analysis by Harry Masters, 2016, in course of publication

Load control + PVs = grid optional





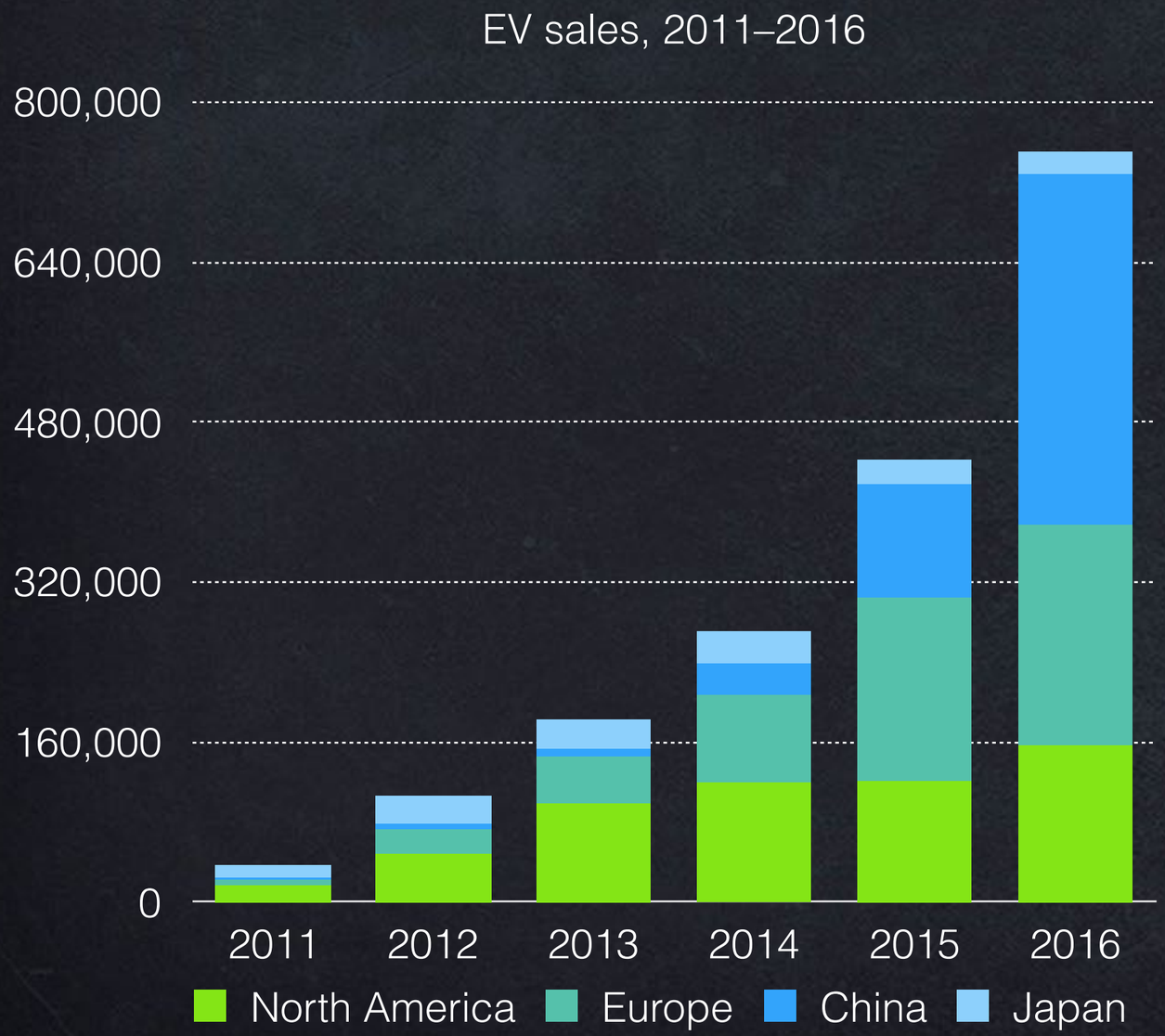
Uncontrolled: ~50% of solar PV production is sent to the grid, but if the utility doesn't pay for that energy, how could customers respond?

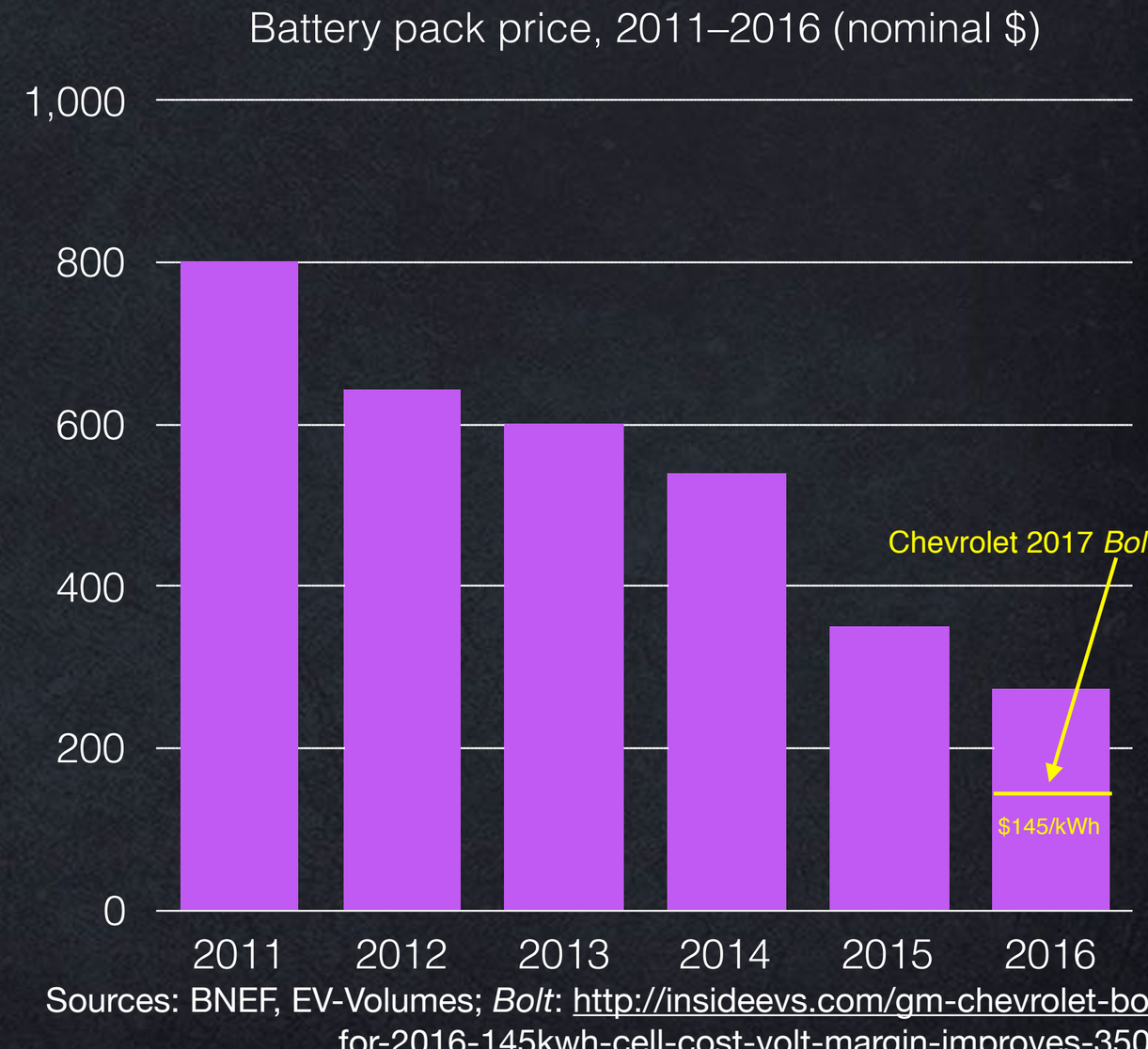
Controlled: flexible load enables customers to consume >80% of solar PV production onsite. The utility loses nearly all its windfall and most of its ordinary revenue.

Source: RMI analysis "The Economics of Load Flexibility," 2015

Accelerating EV growth and declining battery cost

Global EV sales are growing ~60% per year, while U.S. EV sales flatten, with battery price approaching or below $200/





Sources: BNEF, EV-Volumes; *Bolt*: http://insideevs.com/gm-chevrolet-bolt-for-2016-145kwh-cell-cost-volt-margin-improves-3500/

Volume Production of Electrified Carbon-Fiber Cars

Hypercar *Revolution* 5-seat hybrid SUV
2000 virtual design (RMI with two Tier Ones)
67 mi/USgal (petrol) or 114 mpge (H_2), 1,887 lb (–53%)
3.6 L/100 km (petrol) or 2.1 (H_2), 857 kg (–53%)

Toyota *1/X* 4-seat plug-in hybrid
2007 concept car
131 mpge, 926 lb (–70%)

VW *XL1* 2-seat plug-in hybrid
2014 low-volume production
235 mpge, 1,759 lb
0.9 L/100 km, 798 kg

BMW *i3* 4-seat battery-electric hatchback
2013– midvolume production, $41–45k
124 mpg, 1.9 L/100 km
185+-mile (300-km) range w/extender option

From PIGS to SEALS

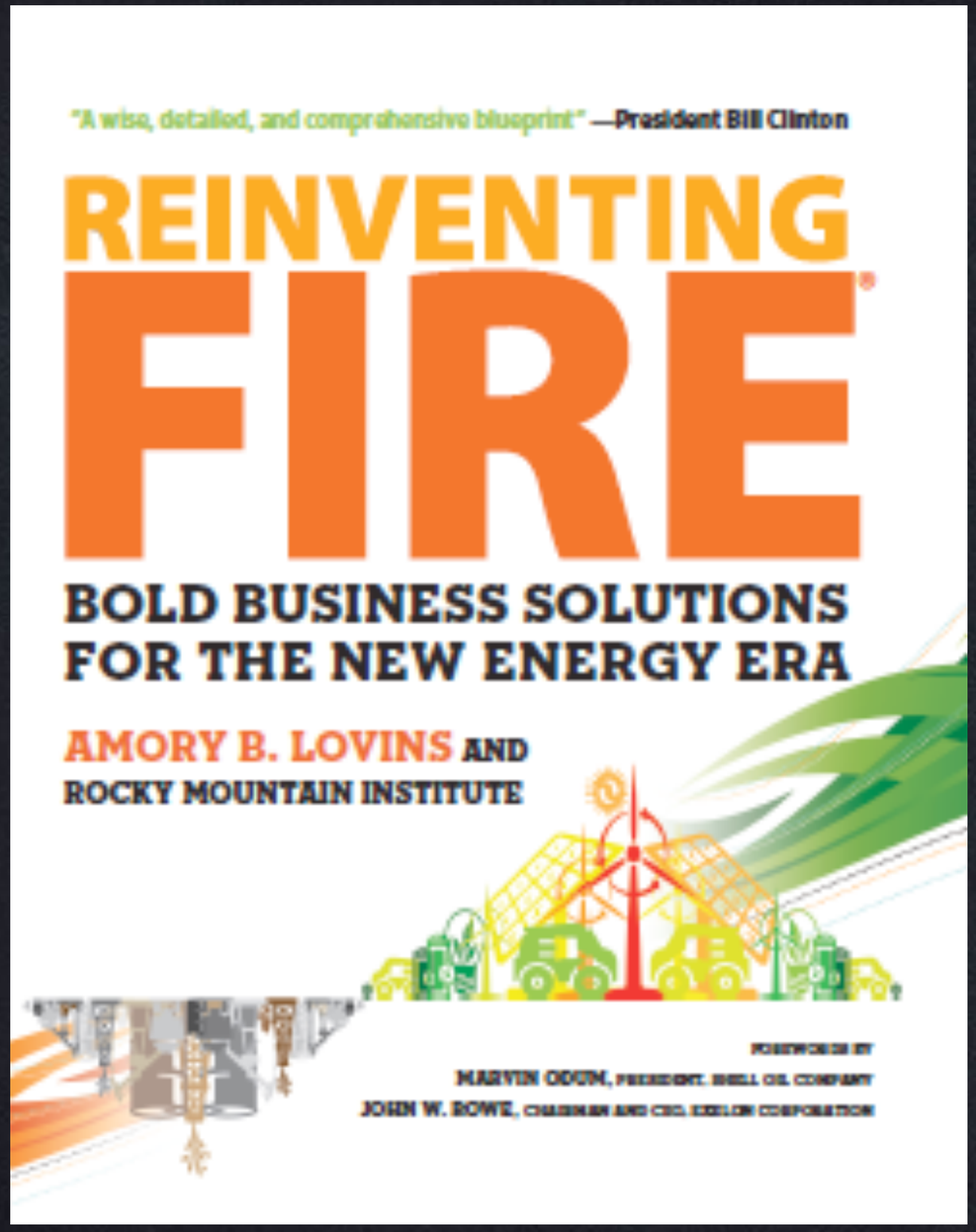
Personal **I**nternal-combustion **G**asoline **S**teel

Shareable **E**lectric **A**utonomous **L**ightweight [mobility-as-a-]**S**ervice

中华人民共和国
国民经济和社会发展第
十三个五年规划纲要
2016年03月17日

3-4x Energy Productivity in Buildings, 2x in Industry

Same or better services


"A wise, detailed, and comprehensive blueprint" —President Bill Clinton
REINVENTING
FIRE
BOLD BUSINESS SOLUTIONS
FOR THE NEW ENERGY ERA
AMORY B. LOVINS AND
ROCKY MOUNTAIN INSTITUTE
MARVIN ODUM, PRESIDENT, SHELL OIL COMPANY
JOHN W. ROWE, CHAIRMAN AND CEO, EXELON CORPORATION


REINVENTING
FIRE
重塑能源
新能源世纪的商业解决方案

$5T

in savings

+158%

bigger economy

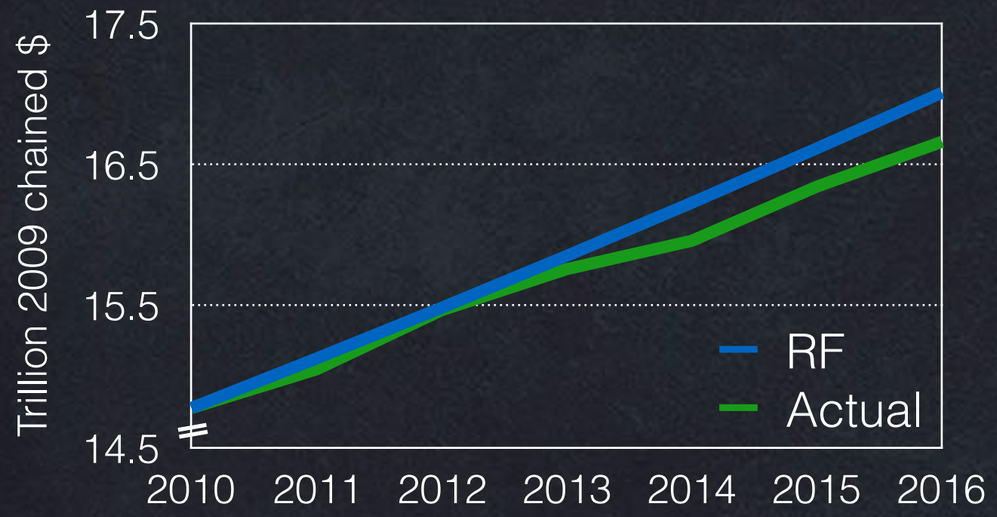
0

oil, coal, nuclear

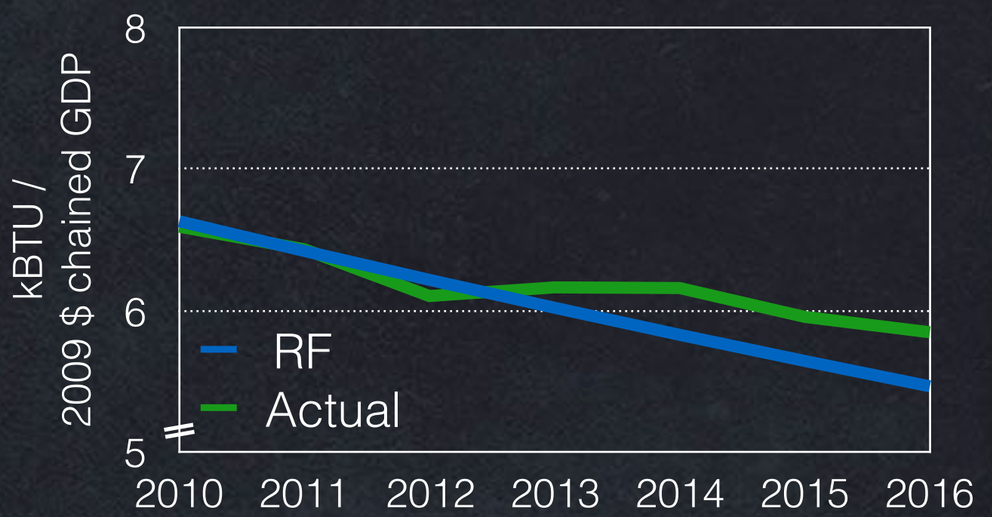
2010–2016 U.S. progress toward *Reinventing Fire's* 2050 goals

Actuals (USEIA) are not weather-adjusted. *Reinventing Fire* progression based on constant exponential growth rate.

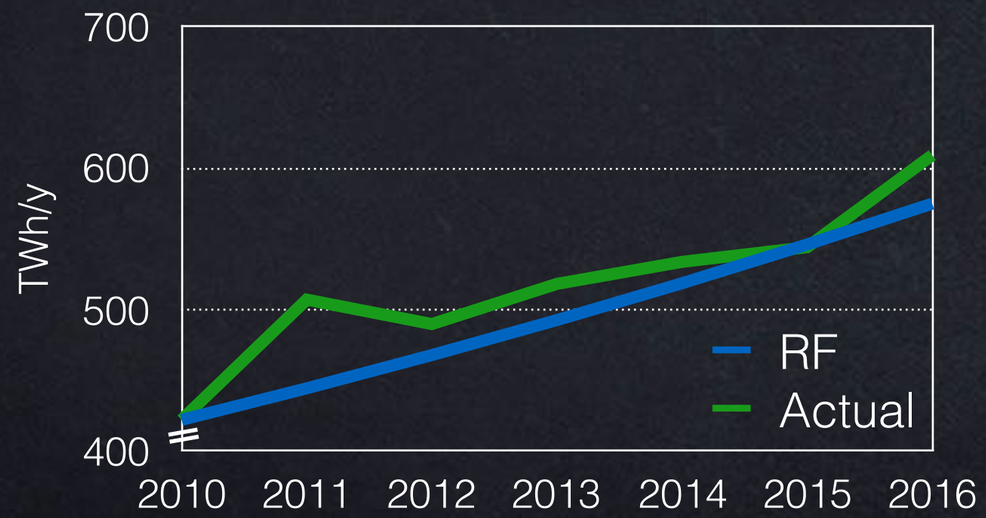
GDP



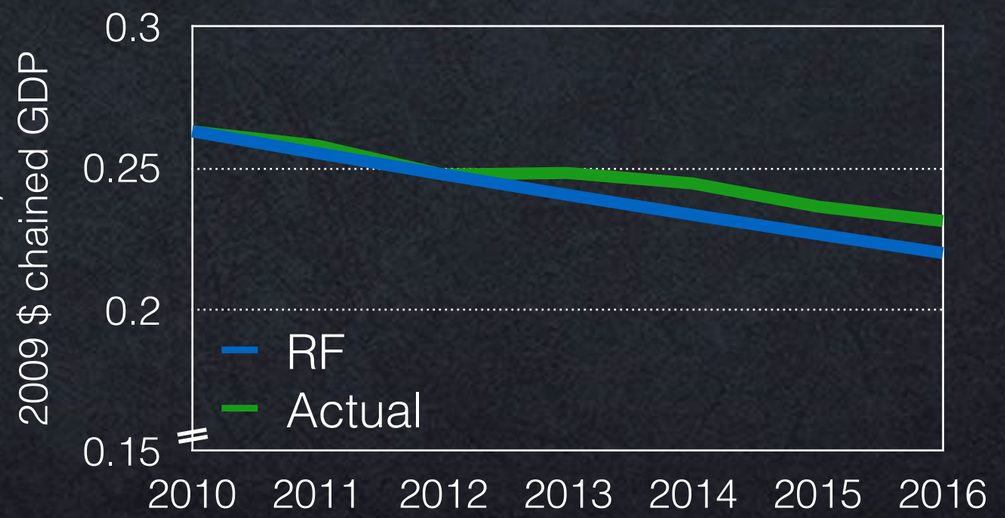
Primary energy intensity



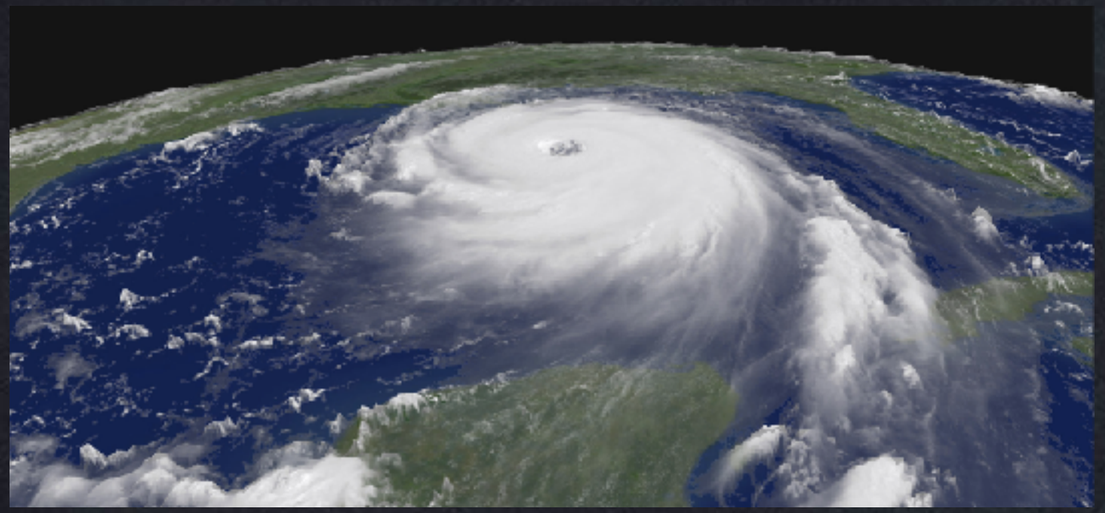
Renewable electricity generation



Electric intensity

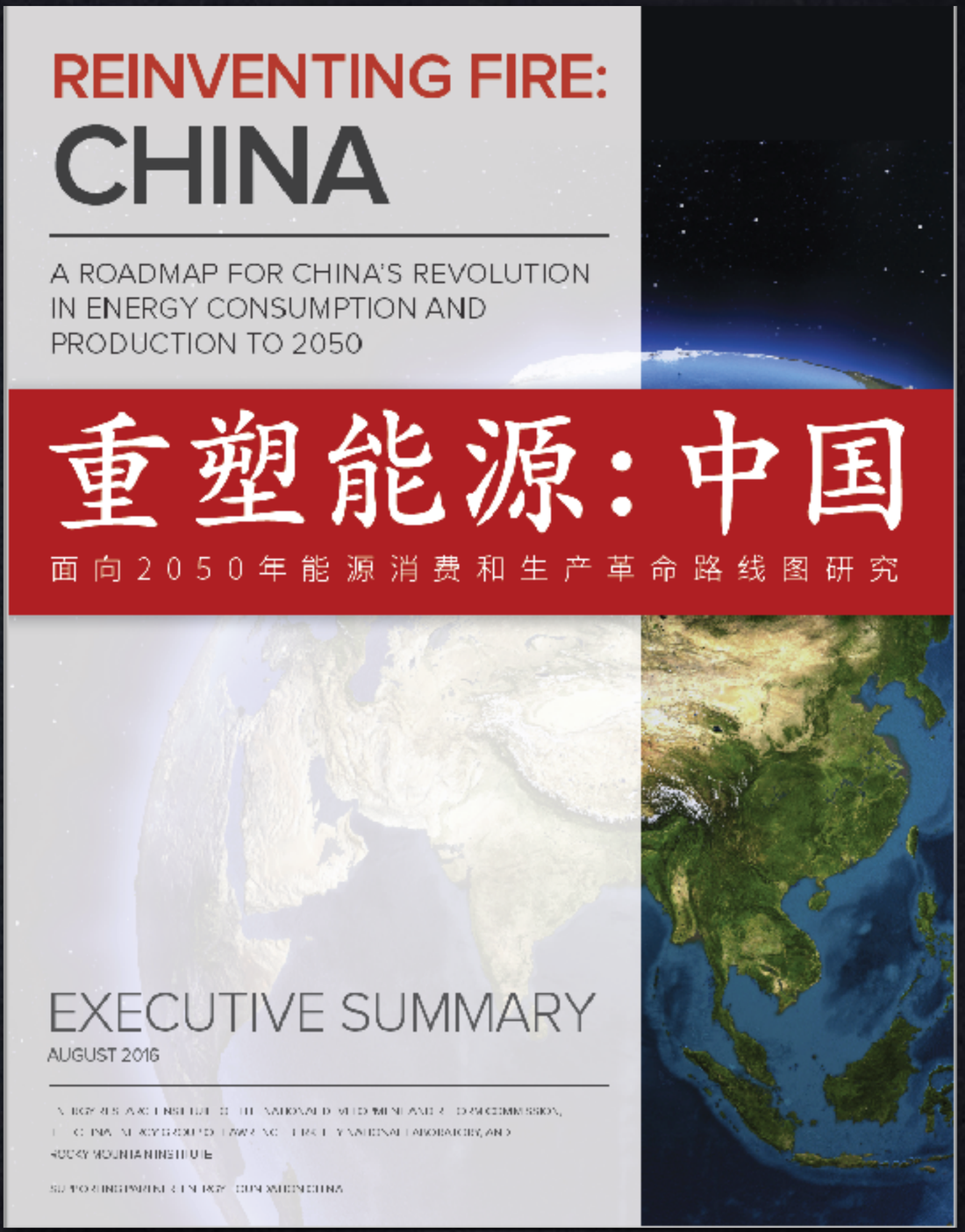


Solutions to:



REINVENTING FIRE®

BOLD BUSINESS SOLUTIONS FOR THE NEW ENERGY ERA



RMB 21T
2010 NPV

in savings
经济节约

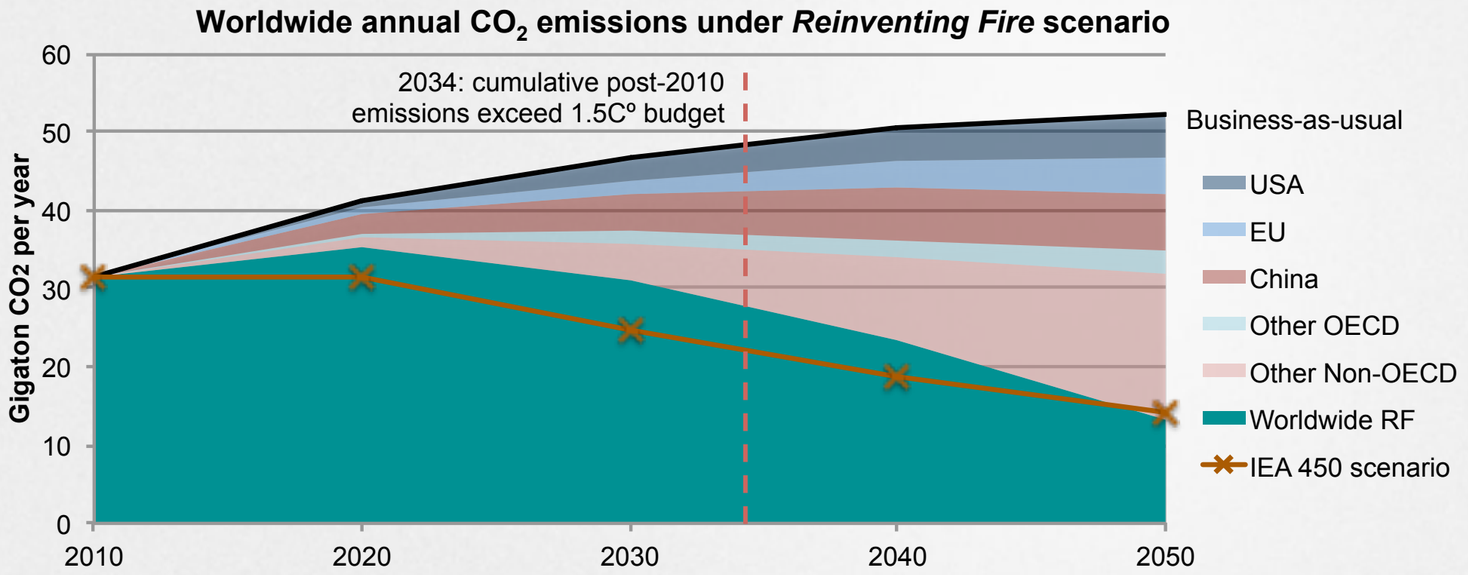
+587%

bigger GDP
经济规模

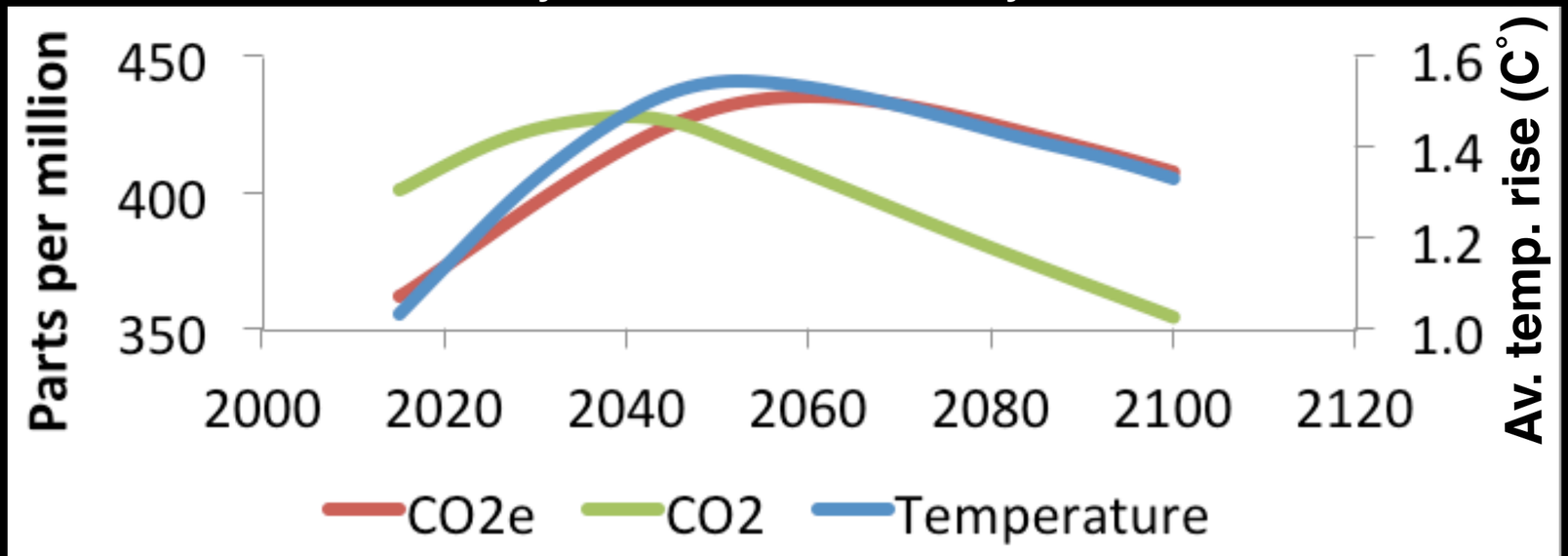
42%

less carbon
碳排放减少

Reinventing Fire applied worldwide will keep within the 2010–2050 carbon budget for 50% probability of 2C°



…and with conservatively assessed natural-systems carbon removal…



Value > Price > Cost

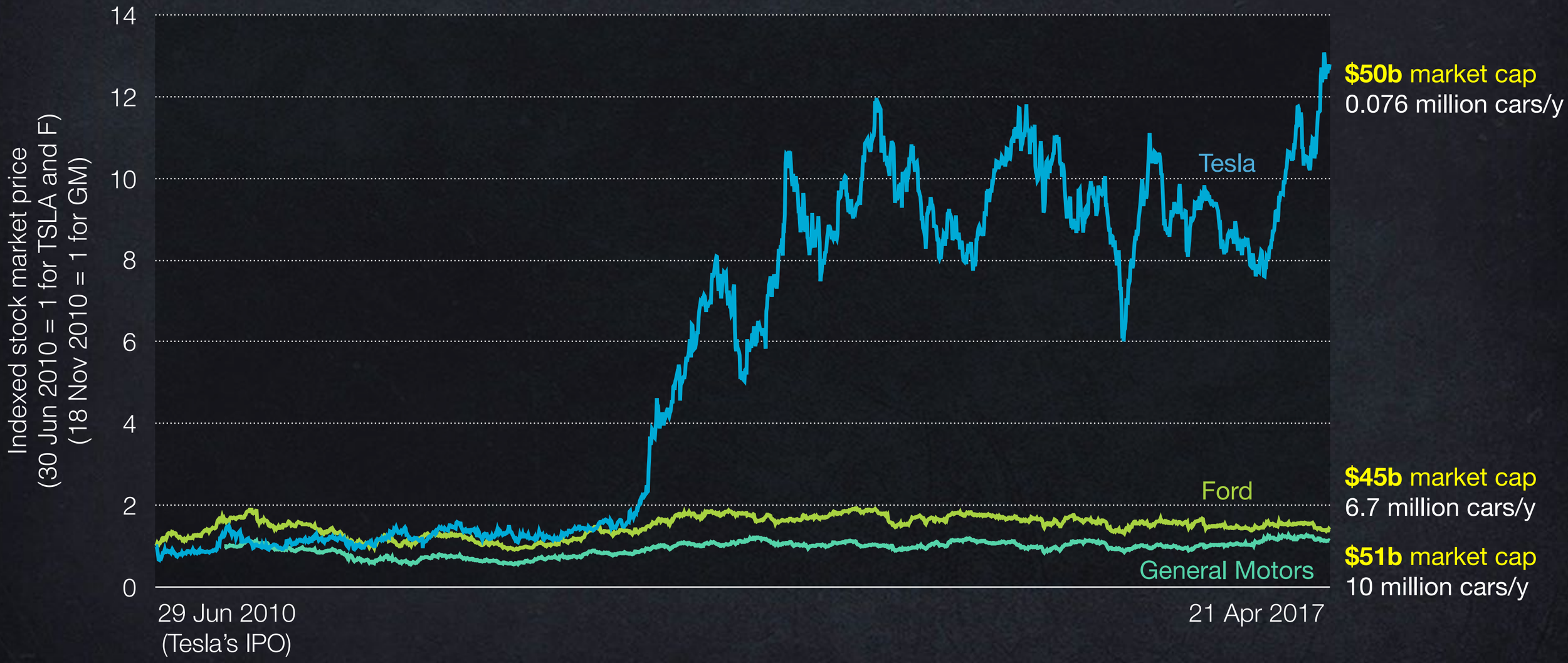
Easter Parades on Fifth Avenue, New York, 13 years apart

1900: where's the first car?

1913: where's the last horse?

Images: L, National Archive, www.archives.gov/research/american-cities/images/american-cities-101.jpg; R, shorpy.com/node/204.
Inspiration: Tona Seba's keynote lecture at AltCar, Santa Monica CA, 28 Oct 2014, http://tonyseba.com/keynote-at-altcar-expo-100-electric-transportation-100-solar-by-2030/

New and old automakers



From the Age of Carbon to the Age of Silicon

Profitable Climate Protection with Development and Security

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